SUBSURFACE DISPOSAL OF ACID MINE WATER

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Introduction

While the mining industry has concerned itself with mine drainage in the past, recent legislation in Pennsylvania has accented the problem. Reclassifying acid mine drainage as an industrial waste and prohibiting its disposal into any stream, clean or polluted, were the two basic changes in the new Clean Streams Bill that caused a re-appraisal of an old and perplexing problem. With millions of gallons of mine water containing sulfuric acid, ferrous sulfate and ferric hydroxide being discharged annually in amounts of acidity varying from 50 to 20,000 ppm, research has been accelerated in an attempt to obtain a solution.

Iron disulfide, FeS_2, associated in surrounding rock strata as well as in the coal seam itself, undergoes chemical change in the presence of air and water, resulting in acid water formation. While there is some disagreement as to the exact mechanism, the following reactions are generally accepted:

$$2FeS_2 + 2H_2O + 7O_2 \longrightarrow 2FeSO_4 + 2H_2SO_4 \qquad (1)$$

$$4FeSO_4 + H_2SO_4 + O_2 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O \qquad (2)$$

$$Fe_2(SO_4)_3 + 6H_2O \longrightarrow 2Fe(OH)_3 + 3H_2SO_4 \qquad (3)$$

There is no typical acid mine water and it is a more complex solution than the above equations would indicate. Not only does the ferrous to ferric iron ratio vary, but pH is not a true indicator of total acidity. Additional ions such as silica, aluminum, manganese, calcium and magnesium are present, as well as autotrophic bacteria which are thought to accelerate the formation of acid.

While coal associated iron disulfide usually is isolated from oxygen and water in its natural environment in the earth, mining the coal seam removes support from the overlying strata inducing caving. An influx of water and air, together with the exposure of additional acid-producing materials, provide all of the necessary ingredients for the above reactions to occur. Even then, if the water could be removed from the mine immediately, acid water need not be produced. Unfortunately, the caved areas become inaccessible and the overflow is the major contributor of acid mine water. It becomes obvious that any cessation of mining activity would aggravate the problem, since at least in active mines water is pumped regularly and thus exposure time is minimized.

Some people have advocated that sufficient coal be permitted to remain in place to prevent caving. Aside from the economic loss of the coal left behind, other factors must be considered. In many coal fields the systematic pulling of pillars and controlled caving is the only way that excessive rock pressures are relieved and the excavation can be maintained. Another risk to leaving pillars behind is that spontaneous combustion can lead to a mine fire. With mines going to greater depth because of depletion of shallower deposits, longwall mining will increase. This system more than any other requires controlled caving, thus the problem could become aggravated.

The Coal Research Board of the Commonwealth of Pennsylvania is supporting research projects encompassing a wide variety of studies including: destruction of acid-forming bacteria by phages; economic removal of iron; more efficient neutralization of acid water on a commercial scale; purification of acid water by a distillation process; and the subsurface disposal of acid mine water. This paper is concerned with the last project listed. While better abatement measures will minimize some of the pollution, without doubt there always will be some water that must either be treated or disposed of in a prescribed manner. While the authors make no claim that deep well disposal is a panacea for mine acid problems, nevertheless it deserves close scrutiny as one solution to this problem.

Present Applications of Subsurface Disposal

Subsurface disposal involves removing unwanted materials from their original environment and placing them in isolated subterranean zones. Permanent removal of undesired liquid water generally is accomplished by using injection wells to transport the material to the disposal zone.

The petroleum industry first employed subsurface disposal in the early part of the twentieth century to dispose of oil field brines[(1)]. During the past ten years, other industries have adopted this method to dispose of manufactured wastes. Injection wells are presently being used in the drug, chemical, steel, and paper manufacturing industries[(2)]. Radioactive material from nuclear plants also is being injected into disposal wells.

Injection wells are drilled from the surface to the geologic formation selected as the disposal zone. Disposal wells are drilled and completed in the same manner as gas and petroleum wells, and waste travels down the well through a non-corrosive injection tube. Surface facilities associated with injection wells consist of a waste gathering and storage system, filtering equipment, and one or more pumps. Multi-barreled displacement pumps usually are used with injection wells.

The rate at which a disposal well can accept fluid depends upon the fluid properties, rock properties, the size of the well and the pressure gradient in the system. Pumps provide the pressure necessary to push the waste into the disposal zone. The necessary injection pressure may be calculated from the following relationship:

$$P_i = P_f - P_s + P_l \qquad (4)$$

where P_i = Injection pressure from pump
P_f = Well bottom formation pressure
P_s = Pressure of fluid column in well
P_l = Friction loss in injection tube

[(1)]References at end of paper.

Formation pressure (P_f) cannot be measured until the well has reached the disposal zone and, even then, an accurate measurement is not always possible. An estimate of the formation pressure can be made by multiplying the well depth by the geologic pressure gradient. The generally accepted pressure gradient is one pound per square inch pressure per foot of depth. The fluid column pressure (P_s) can be calculated from the well depth and the fluid density. Friction loss (P_l) can be calculated from well depth, injection tube material and size, and the flow rate. Flow rate into the disposal formation is usually not directly proportional to injection pressure. At higher pressures, incremental pressure increases result in a proportionately greater flow rate.

If it becomes desirable to increase flow rate for a given pressure, the formation properties may be altered. Several methods of well stimulation are practiced in the petroleum industry to achieve a more efficient well(3). These practices are hydraulic fracturing, nitro-shooting, well perforating, and acidizing. Hydraulic fracturing is the most popular of these methods.

Despite increased application, disposal wells still are not too numerous. Only six waste injection wells exist in Pennsylvania. This scarcity results from the large financial investment that must be made before the success of the installation can be ascertained. The drilling, casing, and testing of a 2000 feet deep disposal well costs approximately $70,000. Although an analysis of an injection well's performance cannot be predicted before field trials, some conditions are more favorable to subsurface disposal than others.

Pertinent Geologic Factors

The main factor to be considered when contemplating the establishment of a disposal well is the presence of the proper geologic formations. The disposal formation must have a large enough storage capacity to contain the total volume of fluid that will be injected during the life of the well. This capacity depends upon the area and thickness of the formation and upon the effective porosity of the formation. A disposal formation should also be surrounded by relatively impermeable rocks to prevent migration of the waste away from the disposal zone. The disposal zone, however, should be very permeable to allow rapid flow of the waste away from the well with a minimum expenditure of pumping energy. Finally, a potential disposal zone should not contain usable ground water or any economic fuel or mineral deposit that could be contaminated by the waste.

The bituminous coal fields of central and western Pennsylvania lie in a region of stratified sedimentary formations. Rock types are sandstones, limestones, shales, siltstones and claystones, and all vary in areal extent and thickness. Shales, siltstones, and claystones are very impermeable rocks of low porosity and generally are ruled out. The two remaining rock types, if occurring in large enough bodies, can be considered potential disposal reservoirs.

Many sandstone beds are quite thick, underlie large areas, and often have high values of porosity and permeability. Fluid flow through a sandstone brings the liquid into intimate contact with the rock, causing a maximum amount of contact between the waste and the formation. Sandstones are largely silica, a comparatively non-reactive element.

Limestones generally exhibit lower permeability and porosity than sandstones and are often partially dissolved by ground water, forming a series of subterranean channels. Fluid flow in these channels is similar to flow in an irregular system of pipes. Although formation to fluid contact is minimal, the extent of the fluid migration is difficult to determine. Limestone is calcium carbonate, a more reactive compound than silicon dioxide.

General geologic structural information is available for many of the larger rock units in central and western Pennsylvania. Detailed lithologic information is very limited, however, and any area being considered for an injection well site should be thoroughly evaluated, even to the extent of a core drilling program. Many well driller's logs are available for the above area, but experience has shown that these often do not contain reliable lithologic information.

Waste Properties Vital to Subsurface Disposal

The experience of companies using injection wells has shown that wastes which are to be injected into porous beds ideally should have the following properties:

1. A pH less than the formation water
2. No suspended solids
3. Low viscosity
4. Low metal content
5. High specific gravity
6. No self-polymerizing materials
7. No dissolved gases
8. No bacteria

The waste should also be chemically stable and compatible with the formation rock and fluids. The main concern in injecting wastes into a porous formation is the possibility of plugging the disposal zone with suspended particles carried in the waste or with precipitates resulting from chemical reactions occurring in the disposal zone. Recovery of a plugged well is expensive and time consuming.

Acid mine water, while having a low pH and viscosity and containing no self-polymerizing materials, does not meet the other criteria. Of particular concern are the presence of suspended solids, bacteria, dissolved gases, and concentrations of iron. Acid mine water is not chemically stable and its compatibility with the formation will not be known until samples of the rock and connate water are available. It is felt that these problems, although difficult, are not insurmountable and each can be solved.

Specific Acid Mine Water Disposal Problems

Autotrophic bacteria are present in acid mine water. Research indicates that these bacteria collect on iron particles and form colonies as large as 50 microns in diameter[4]. Particles of this size could easily plug a sandstone face. In other disposal wells bacterial plugging has been eliminated by adding a bacteriacide to the waste before injection. Addition of an effective bacteriacide to acid mine water would kill the bacteria and prevent colonization.

Dissolved gases are detrimental because they promote corrosion and provide material for unwanted chemical reactions. Oxygen and hydrogen sulfide which can occur in mine water are particularly undesirable, as both can react with metallic ions to produce precipitates. Large volumes of dissolved gases can lower pump efficiencies. The amount of dissolved gas present in acid mine water can be kept minimal by assuring that the water is collected and stored prior to injection with the least possible exposure to air.

Removal of suspended particles in the waste is also an important consideration, particularly if the disposal formation is a sandstone. Pre-injection filtering should remove particles down to one micron. Coated pressure leaf filters are normally used in this application. If surface filtering facilities are not provided, the disposal formation may act as a filter and become progressively less permeable as it becomes plugged by the suspended particles.

Chemical reactions between acid mine water and the formation water may be prevented by injecting a non-reactive buffer zone between these two liquids. The material selected for the buffer zone, which will physically separate the formation water and the mine water, should be low in cost and chemically inert with respect to the mine water, the formation water, and the rock. After waste injection has commenced, liquid diffusion and dispersion will occur in the formation. This activity will eventually cause the formation water and the waste to contact each other. If a sufficient buffer zone has been injected, this mixing will not occur until near the end of the life of the well. When contact is established, the waste and the formation water will be diluted by the buffer liquid.

The chemical instability of acid mine water may cause intraformational precipitation. Hopefully, this possibility is reduced by the lack of oxygen in the disposal zone. Possible oxidation of ferrous iron to ferric, and subsequent precipitation of ferric hydroxide is of particular concern as this is a gelatinous material. The oxidation state of iron is a function of pH, therefore, this reaction may be eliminated by lowering the pH of the mine water prior to injection to deep the iron in the ferrous state. Other anti-precipitation agents used in disposal wells are citrates and sodium tripolyphosphate(5).

Conclusions

It is accepted that many variable factors are involved in the installation of a subsurface disposal well. Theoretical solutions are available for many of the foreseeable problems, but several unexpected developments may occur. While past experience with other disposal wells may be used as a guide to developing a new well, it can not be expected to provide answers for all problems that may arise. Each disposal well will have to be approached as an individual engineering problem.

References

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